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16. ABSTRACT

The body of information presented in this paper is directed to policy makers and administrators involved in the evaluation and assessment of damages caused by oxidant air pollution on human health and welfare and of possible benefits of control.

To provide a comparison of some of the benefits that can be obtained by reducing photochemical oxidant levels, estimated health costs were derived from data relating adverse health effects to hourly oxidant concentrations. Hourly oxidant or ozone concentrations were measured at approximately 400 monitoring stations scattered throughout the U.S. Most of these sites were located in major urban areas or in other areas where high oxidant concentrations prevailed. Estimates of populations at risk and per capita health costs were generated for those areas where oxidant data was available.

During the period 1971-1973, nearly two-thirds of the U.S. population resided in areas where the hourly primary standard for oxidants of 160 ug/m^3 was exceeded. The total annual health cost attributable to oxidants was estimated to range from $120 to over $240 million in the U.S.

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Ambient Oxidant Exposure and Health Costs in the United States—1973

Donald G. Gillette
U.S. Environmental Protection Agency

The body of information presented in this paper is directed to policy makers and administrators involved in the evaluation and assessment of damages caused by oxidant air pollution on human health and welfare and of possible benefits of control.

To provide a comparison of some of the benefits that can be obtained by reducing photochemical oxidant levels, estimated health costs were derived from data relating adverse health effects to hourly oxidant concentrations. Hourly oxidant or ozone concentrations were measured at approximately 400 monitoring stations scattered throughout the U.S. Most of these sites were located in major urban areas or in other areas where high oxidant concentrations prevailed. Estimates of populations at risk and per capita health costs were generated for those areas where oxidant data was available.

During the period 1971–1973, nearly two-thirds of the U.S. population resided in areas where the hourly primary standard for oxidants of 160 $\mu g/m^3$ was exceeded. The total annual health cost attributable to oxidants was estimated to range from $120 to over $240 million in the U.S.

Estimates of the possible social costs and health benefits obtainable from reducing oxidant levels are needed to guide environmental policy decisions in the U.S. To provide a more definitive estimate of the costs, the study described herein employs available health effects data, explicitly assigns costs to different morbidity states, defines the population exposed to varying oxidant levels, and generates regional and national estimates of the annual health costs attributed to oxidants in the U.S.

Research Methods and Costs

The development of reasonable estimates of health costs attributed to oxidants requires information (1) on the proportion of the population that is annoyed, disabled, or incapacitated at different air quality levels; (2) on the geographical and temporal distribution of air quality and receptor populations; and (3) on climatic and other social, physiological, and environmental factors that may influence the amount of damage or insult. Finally, to define economic costs, effects data on human health or well-being must be translated into economic values.

Dr. Gillette is an economist in The Health Effects Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. This is a revised version of Paper No. 75-07.8 which was presented at the 68th Annual Meeting of APCA at Boston in June 1975.

Hourly oxidant readings were obtained from the E.P.A. air quality data bank. The data bank contained data from 200 or more monitoring stations located primarily in heavily populated or defined problem areas. Estimates of the population at risk and exposures were defined by the population base and by the frequency distribution of hourly oxidant levels measured at monitoring sites within each of the Air Quality Control Regions (AQCR).

Oxidant Exposure and Health Effects

Numerous studies have suggested that photochemical oxidants are harmful to human health. Some of the more pronounced health effect symptoms that have been observed are: irritation of the eyes, headaches, aggravation of chronic respiratory and other disease symptoms, increased asthma attacks, and decreased performance levels of athletes and other individuals engaged in strenuous activities. Other effects, observed in animal and laboratory experiments, are: increased number of mutations, impaired fetal survival, altered physiological processes, and increased susceptibility to acute respiratory diseases. A summary of the threshold levels of oxidants associated with various health effects is presented in Table I. The threshold levels were obtained from the Air Criteria Document for Photochemical Oxidants[1] and other reports.

Estimates of the percentages of the total U.S. population residing in areas where the primary hourly oxidant standard was either met or exceeded during 1973 are presented in Table II. The primary standard, established principally to mitigate adverse health effects, states that the hourly concentration levels of 160 $\mu g/m^3$ shall not be exceeded more than once a year. During 1973, over 60% of the U.S. population resided in areas where this standard was being exceeded.

Health Damage Functions

Estimates of the proportion of a subpopulation group likely to exhibit morbidity symptoms when exposed to various oxidant levels are presented in Table III. These estimates, obtained from a recent study performed by the California Air Resource Board,[11] were based upon responses solicited from a panel of medical and air pollution experts. Different states of morbidity—discomfort, disability, and incapacity—were defined, and estimates of the population falling within each of the morbidity states at various pollutant concentrations were given.

Different sets of morbidity cost factors presented in Table IV were used to derive low, medium, and high estimates of health costs. Per capita damage functions relating morbidity costs to oxidant levels for each of these estimates is shown in

Figure 1. The differences between the functions are due to differences in the assumed set of morbidity cost factors, whereas the movement along any of the functions reflects the change in the proportion of the population adversely affected at varying oxidant concentrations. The above relationship, with an assumed health effects threshold level (100 $\mu g/m^3$/hr), is described by the following logarithimic function;

$$\ln Y_{k,j} = A_j + B \ln (X_k - 100) + e$$

where

$Y_{k,j}$ = estimated per capita health cost per hourly oxidant level k for the jth function (low, medium, and high estimates)
A_j = intercept value of health costs at the threshold level not attributed to oxidants for the jth function
B = percent change in per capita health costs with respect to the percent change in hourly oxidant levels
$(X_k - 100)$ = hourly oxidant concentrations less threshold level
e = random error

Health Costs of Oxidant Exposure

An annual health cost estimate was derived for each ACQR that had available oxidant data. This annual estimate was obtained by determining the number of hours per year that various oxidant levels were observed, multiplying these hours by the per capita estimates of hourly oxidant exposure costs as defined by the damage functions, and summing the total costs of all the exposure hours. These estimates were then multiplied by the respective population bases of AQCR's and aggregated to generate local, regional, and national estimates.

Table I. Estimated exposure thresholds for adverse effects due to photochemical oxidants.

Effect	Threshold $\mu g/m^3$	Threshold ppm	Reference
Headaches without fever	100	0.05	Hammer[2] *et al.*
Irritation of eyes	200 to 300	0.10 to 0.15	Hammer[2] *et al.*
Decreased cardiopulmonary reserve (Healthy adults)	240 to 740	0.12 to 0.51	Wayne[3] *et al.*
Aggravation of certain anemias	400 to 500	0.20 to 0.25	Brinkman[4] *et al.*
Aggravation of asthma	500	0.25	Schoettlin[5] *et al.*
Aggravation of chronic lung disease	500	0.25	Remmers and Balchum[6]
Irritation of respiratory tract (Healthy adult)	500 to 600[a]	0.25 to 0.30	Kleinfeld[7] *et al.*
Increased susceptibility to acute respiratory disease	160[b]	0.08	Coffin[8] *et al.*
Impaired fetal survival	200 to 400[b]	0.10 to 0.20	Brinkman[4] *et al.*
Risk of mutations	400 to 600[b]	0.20 to 0.30	Zelac[9] *et al.*
Decreased visual acuity	400 to 1000[a]	0.20 to 0.50	Lagerwerff[10]

[a] Involves exposures of three to seven hours daily for several weeks.
[b] Based solely on animal experiments involving exposures of three to seven hours daily for several weeks.

Table II. Estimated frequency and percent of population exposed to oxidant levels in excess of hourly oxidant standard by regions (1973).[a]

Federal[b] region	Frequency of hours exceeding oxidant standard: 0.0%	>0.0% ≤1.0%	>1.0% ≤2.0%	>2.0% ≤3.0%	>3.0	Total by region
			(percent)			
I	28	20	—	29	23	100
II	1	14	67	18	—	100
III	28	20	—	36	16	100
IV	60	19	17	4	—	100
V	46	35	8	—	11	100
VI	41	9	3	13	34	100
VII	52	26	22	—	—	100
VIII	63	15	—	22	—	100
IX	2	27	6	—	65	100
X	45	55	—	—	—	100
All Regions	36	22	16	10	16	100

[a] Estimates based upon population and oxidant readings from 247 air quality control regions in the United States.
[b] The states or territories included by Regions are:
I CT, ME, MA, NH, RI, VT
II NJ, NY, PR, VI
III DE, DC, MD, PA, VA, WV
IV AL, FL, GA, MS, KY, NC, SC, TN
V IL, IN, MI, MN, OH, WI
VI AR, LA, NM, OK, TX
VII IA, KS, MO, NE
VIII CO, MT, ND, SD, UT, WY
IX AZ, CA, HI, NV, Guam, American Samoa
X WA, OR, ID, AK

The health costs attributed to photochemical oxidants during 1973 in the U.S. ranged from less than $125 million to approximately $250 million, with a median estimate of $183 million. Approximately 5% of the total possible person hours of oxidant exposure in 1973 was in excess of the health effects threshold value of 100 $\mu g/m^3$. Most of the health costs attributed to oxidant exposure occurred in Southern California.

Previous estimates of health costs associated with photochemical oxidants[12-15] have ranged from less than $100 million to more than $1 billion/yr in the U.S. The estimate generated in this study falls within this range. Furthermore, a 20% increase in oxidant levels throughout the U.S. was projected to result in more than doubling present health cost estimates, whereas a 20% reduction was projected to reduce health costs to about one-fourth of the present level.

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Table III. Estimated percent of population affected and average per capita health costs for populations exposed to different hourly oxidant concentrations.

Health condition	Cost factor[a] $/hr	Oxidant exposure level: 600 μg/m³/hr Population affected[b] %	600 μg/m³/hr Avg. cost per capita $/hr	800 μg/m³/hr Population affected[b] %	800 μg/m³/hr Avg. cost per capita $/hr	1000 μg/m³/hr Population affected[b] %	1000 μg/m³/hr Avg. cost per capita $/hr
				Low cost estimate			
Discomfort	1.00	10.0	0.10	25.0	0.25	50.0	0.50
Disability	5.00	3.0	0.15	9.0	0.45	18.0	0.90
Incapacity	25.00	0.0	0.00	1.0	0.25	2.0	0.50
		13.0	.25	35.0	.95	70.0	1.90
				Medium cost estimate			
Discomfort	1.50	10.0	0.15	25.0	0.375	50.0	0.75
Disability	7.50	3.0	0.225	9.0	0.675	18.0	1.35
Incapacity	37.50	0.0	0.00	1.0	0.375	2.0	0.75
		13.0	.375	35.0	1.425	70.0	2.85
				High cost estimate			
Discomfort	2.00	10.0	0.20	25.0	0.50	50.0	1.00
Disability	10.00	3.0	0.30	9.0	0.90	18.0	1.80
Incapacity	50.00	0.0	0.00	1.0	0.50	2.0	1.00
		13.0	.50	35.0	1.90	70.0	3.80

[a] Cost factors are estimates of cost/hour that an individual may incur when experiencing different health conditions. Differences between Low, Medium, and High Cost Estimates were derived by changing these assumed Base Factors.
[b] Estimated percent of population experiencing morbidity at different exposure levels were obtained from the CARB report.

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Table IV. Estimated total and per capita oxidant health costs by EPA Regions—1975.

EPA Regions	Estimated health costs: Low Total costs	Low per capita	Medium Total costs	Medium per capita	High Total costs	High per capita
	($1,000)	($)	($1,000)	($)	($1,000)	($)
I	1,008	0.08	1,512	0.12	2,016	0.16
II	8,200	0.31	12,300	0.47	16,400	0.62
III	12,323	0.51	18,484	0.77	24,646	1.02
IV	1,922	0.06	2,883	0.09	3,844	0.12
V	1,680	0.04	2,520	0.06	3,360	0.08
VI	14,548	0.72	21,822	1.08	29,096	1.44
VII	4,134	0.36	6,201	0.54	8,268	0.72
VIII	3,786	0.65	5,679	0.98	7,572	1.30
IX	74,710	3.22	112,065	4.83	149,420	6.44
X	1	<.01	2	<.01	3	<.01
Total	122,312	0.58	183,469	0.88	244,625	1.17

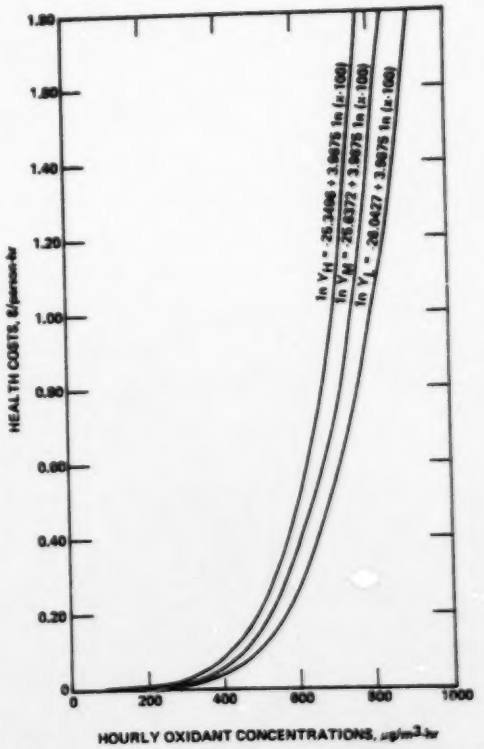

Figure 1. Per capita damage functions from hourly oxidant exposure used in deriving low, medium, and high health cost estimates.